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MAN'S INFLUENCE ON LAKE ERIE

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ABSTRACT

Conversion of northwestern Ohio's Great Black Swamp to farm land during the last half of the nineteenth century had a profound, but scantily documented influence on Lake Erie. Silts, once largely filtered out by the swampland vegetation, were, with the destruction of that vegetation, carried into Lake Erie, where their effect in reducing light penetration has significantly altered the lake's biota.

More recently a spectacular enhancement of plant nutrients, especially phosphorus, which has increased five-fold since 1948, has supported nuisance levels of plant growth. This plant growth creates severe oxygen depletion near the lake bottom and is therefore responsible for additional major and undesirable changes in species composition of plant and animal communities. The obvious solution to this problem is the removal of the plant nutrients from the waters before they enter Lake Erie. The "living filter" treatment, in which sewage-plant effluents are filtered through root zones of plant communities, seems most promising.

About 100 years ago, the Maumee River, which flows into southwestern Lake Erie, flowed through the "Great Black Swamp", an area about 40 miles wide by 75 miles long, which bordered the lake in the vicinity of the present city of Toledo, Ohio, and extended westward, up the Maumee drainage basin. Undoubtedly the Maumee waters were effectively filtered and sedimented by the swamp, so that they were largely clarified before they entered Lake Erie. In those days the Cisco (*Leucichthys artedi*) and the Muskellunge (*Esox mosquinongy*) were important fish residents of the Lake, and the Great Black Swamp was an important spawning area for many lake fish species (Langlois 1954). During the latter part of the nineteenth century, this swamp was drained and its ancient lacustrine soils were converted to fertile farm land. This event probably had a more profound influence on Lake Erie than anything that has happened since. After the cultivation of the Maumee watershed had begun, the river became highly turbid, a condition which has continued to exist. Light is quenched so effectively by the suspensoids today that less than five percent penetrates to a depth of one meter and, although the volume of water injected into the Lake by the Maumee is a small fraction of that contributed by the Detroit River, yet the Maumee contributes a major part of the silt loads in western Lake Erie waters (Verduin, 1954).

The changes resulting from draining the Great Black Swamp must have been spectacular. The transition probably occurred in a relatively short span of time, but there are no limnologic data available to document the changes. It is known that important fish species, such as the Muskellunge (which requires swamp spawning grounds) and the Cisco, disappeared, so that the dominant species of commercial and game fish for many years was the Walleye (*Stizostedion vitreum*).

Between the years of 1937-1955, a staff of investigators associated with The Ohio State University was stationed at Put-in-Bay, Ohio (The Franz Theodore Stone Institute of Hydrobiology), on a year-round basis, under the direction of

¹Manuscript received October 11, 1968.

Thomas H. Langlois. Although the University (unfortunately and ill-advisedly) abandoned those year-round investigations in 1955, a considerable amount of sampling has been continued in the spring, summer, and fall, during subsequent years. I was a member of the Stone Institute staff from 1948-1955, and have continued a skeleton research program in subsequent years.

The basin of western Lake Erie (fig. 1) is relatively flat, having an average depth of about 9 m. The water is stirred constantly, even on calm days, by the seiches. The uninodal seiche has a 14-hour period and the average daily rise and fall of water is about 1.5 dm. Such ebb and flow in the western basin causes a horizontal displacement of about 1 km per day. Consequently the western basin has no "hypolimnion" and so, before 1953, the oxygen concentrations on the bottom usually exceeded 6 mg/liter (Chandler, 1940) and the major component of the bottom fauna was a mayfly (*Hexagenia limbata*) usually found in river habitats.

The central and eastern basins are deeper and less thoroughly mixed. They have well-established hypolimnions under summer conditions.

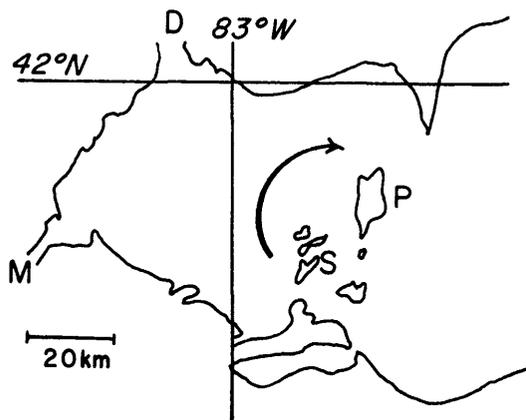


FIGURE 1. Diagram of western end of Lake Erie. The curved arrow shows direction of water movement generated by the seiche. It also marks the region of major convergence between Detroit River (D) and the south shore waters which have received important contributions from the Maumee River (M). P marks Pelee Island and S marks South Bass Island where Put-in-Bay is located.

During the period 1948-1962, significant changes took place in western Lake Erie, as reported by Verduin (1964a). Some of the data presented in that paper are summarized in Table 1. Note that the major components of plankton, benthos, and fish were displaced by new dominant species during that interval. The increased pH maxima reflect enhanced photosynthetic rates, which drive the bicarbonate buffer system toward the carbonate side, thus raising the pH during the peak phytoplankton densities. The CO_2 -uptake rates, determined by measuring pH changes between sunrise and evening, also reveal enhanced photosynthetic rates.

The most striking feature of Table 1, however, is the five-fold increase in available phosphorus. This feature is the more striking when compared with an increase of only about 30 percent in available nitrogen. It seems likely that the nitrogen increase reflects the plant-nutrient contributions attributable to increased sewage releases to the western basin by the expanding human population on the watershed. The discrepantly high increase in available phosphorus is attributed to the widespread substitution of phosphate detergents for ordinary soaps.

The significance of the three major sources of phosphorus enrichment in waters of the United States were evaluated in a symposium on environmental pollution (Verduin, 1967). Analysis of waters from rural watersheds exhibited only one-third as much phosphorus as waters which contained urban effluent contributions. And, in the urban effluents, about two-thirds of the phosphorus content was attributable to detergents.

Perhaps the most significant aspect of the increased phosphates in Lake Erie becomes evident when the ratio of nitrogen to phosphorus (N/P) is considered. In protoplasm, this ratio is about 8 atoms of nitrogen to 1 atom of phosphorus; consequently, a similar ratio in the environment would represent a favorable balance between these important nutrients. In Lake Erie, before 1950, the N/P ratio was 35:1; today it is 9:1. Obviously, the five-fold increase in phosphates

TABLE 1
Biological and chemical changes observed in western Lake Erie during the period 1948-1962

Community	Dominant species 1950	Dominant species in 1961-1962
Phytoplankton	<i>Asterionella formosa</i> <i>Tabellaria fenestrata</i> <i>Melosira ambigua</i>	<i>Fragilaria capucina</i> <i>Coscinodiscus radiatus</i> <i>Melosira binderana</i>
Benthic fauna	<i>Hexagenia limbata</i>	<i>Chironomus plumosus</i>
Fish	<i>Stizostedion vitreum</i>	<i>Perca flavescens</i>
Chemical parameter	Values before 1950	Values in 1960-1961
pH	Maxima of 8.7	Maxima of 9.2
O ₂ near bottom	Minima of 6 mg/l	Minima near zero
CO ₂ uptake per day (surface samples)	32 μmol/l	70 μmol/l
Available nitrogen	260 μg/l	330 μg/l
Soluble phosphorus	7.5 μg/l	36 μg/l

has radically altered the nutrient medium, advancing it from a condition in which phosphorus was relatively scarce to a condition in which its abundance closely matches the availability of nitrogen in the environmental medium.

The most conspicuous and most undesirable changes that have been noted in Lake Erie in recent years are, in my opinion, primarily attributable to the enhanced supply of plant nutrients, especially phosphorus. These nutrients support large phytoplankton crops which, during their decay phase, consume oxygen in the bottom waters at such a rate that even the well-stirred waters of western Lake Erie cannot transport oxygen downward rapidly enough to supply the demand. This explains the catastrophic decline of *Hexagenia* in 1953 (Britt, 1955) and their replacement by "blood-worm" larvae (*Chironomus plumosus*), which can tolerate low oxygen. The enhanced plankton populations also settle into the hypolimnions of the central and eastern basins, creating unprecedented oxygen depletions there.

Perhaps the most obvious nuisance today in Lake Erie is the super-abundance of the filamentous alga, *Cladophora glomerata*. It has been the major component of the plant community in Lake Erie's littoral zone for many years, but in recent years its abundance has expanded enormously. It fouls the fisherman's nets, causing considerable financial loss, and it is deposited on beaches by the ton, where it either decays, the stench destroying the recreational utility of the beach, or it must be hauled away at considerable expense.

There is good evidence that the metabolism of *Cladophora* is closely correlated with the phosphorus supply, based on a comparison of photosynthetic rates made in Lake Erie and in northern Lake Michigan, at the Central Michigan University Biological Station on Beaver Island. The rocks along the Beaver Island shore, which were bathed by waters having less than 5 μg of phosphorus per liter, had no *Cladophora* communities on them. However, *Cladophora* did occasionally wash up on the beach, perhaps originating along the mainland shore, and its photosynthetic rates were measured. These averaged 37 μmol of CO_2 fixed per ml of algal volume per hour, and are closely similar, both to the rates observed by McMillan (McMillan and Verduin, 1953) in western Lake Erie in 1949-50, when phosphorus supplies were about 8 μg /liter, and to rates observed in eastern Lake Erie (during the summer of 1966) where the phosphorus concentration was about 10 μg /liter (Verduin, 1967). But in western Lake Erie, measurement of *Cladophora*-photosynthesis during the past three summers (1966-67-68), in waters having 30-40 μg of soluble phosphorus per liter, produced rates averaging 153 μmol of CO_2 fixed per ml of algae per hour, which is four-fold higher than the rates associated with phosphorus concentrations of 8-10 μg /liter. These observations suggest that the metabolism of *Cladophora* is linearly proportional to the phosphorus supply in the 10-40 μg /liter range of concentration.

Frequently people who have read reports in the public press about Lake Erie's ruination ask, "Is Lake Erie really dead?" "Is it a wet desert?" "Is it an open sewer?" The answer, of course, is "No!" Lake Erie is very much alive. It is simply blessed, or cursed, with a superabundance of plant nutrients. The waters of the Bass Islands region are used extensively for recreation. The Yellow Perch has largely displaced the Walleye in the fisherman's creel, and the midges have displaced the Mayflies, whose spectacular June flights formerly plagued the lake shore cities, but the abundance of these animals certainly contradicts the "wet desert" concept. Moreover, the immense numbers of summer residents and visitors who ski on and swim in these waters do not seem to suffer from epidemics of water-borne diseases. Therefore the open-sewer concept is somewhat exaggerated.

The superabundance of plant nutrients evident in Lake Erie is not an isolated phenomenon. Data gathered by the Federal Water Pollution Control Administration reveal phosphorus levels of 100-200 μg per liter in the major part of the surface waters of the United States. Wherever these waters are retained for a while in ponds and reservoirs, they support nuisance levels of plant growth similar to, or worse than, those encountered in Lake Erie. Investigations are now in progress, especially by the FWPCA, to learn whether Lake Erie is continuing to deteriorate, or whether it is in a more or less steady state. This agency has recently published a study of water and sediment characteristics, comparing data from 1963-1964 with those gathered in 1967-1968 (Table 2). During this four-year interval, soluble phosphorus has increased by about 50 percent. This is not surprising, because the phosphate detergent industry is finding new applications for their product (for example, it is now used widely as a rust inhibitor in the salt applied to city streets in winter). Organic nitrogen increased about 30 percent in the same interval, suggesting that the observed phosphorus increase continues to enhance the production of organic matter. Total phosphorus in the sediment increased by about 40 percent, and ammonia nitrogen increased by a factor of 2.5, suggesting that there are increasing amounts of organic matter depositing on the bottom, where they are attacked by those decay organisms which generate ammonia.

The fact that superabundant plant nutrients are the cause of the most widespread nuisances evident in our lakes and reservoirs is now widely recognized. Sanitary engineers are perfecting chemical methods to remove phosphorus from the effluents of sewage treatment plants, and some states are now requiring installa-

tion of such devices. This attack on the problem is based on a valid interpretation of the Law of Limiting Factors (Verduin 1953, 1964b).

If only one plant nutrient is reduced to near zero levels, plant growth will be severely restricted, although all other factors may be present in abundance. Phosphorus removal would seem to be a wise option because, as was pointed out above, the growth response of aquatic plants to present levels of phosphorus seems to be approximately linear. Therefore, if the phosphorus levels could be reduced by only one-half, or two-thirds, a significant reduction in abundance of aquatic plants, such as *Cladophora*, could be expected. However, I regard such chemical methods as a temporary, stop-gap type of expedient. The long-term solution to this problem, I believe, is indicated by two model treatments. One of these, at Pennsylvania State University, percolates effluent from sewage treatment plants through the root zone of various crop plants (Kardos, 1967). This treatment effectively removes the plant nutrients and converts them to plant products. The other model may be seen near San Diego, California, where effluent from

TABLE 2
*Lake Erie water and sediment characteristics for 1963-64 compared with those observed in 1967-68. Data gathered by the FWP&CA.**

Water characteristic	Years	Western basin	Central basin	Eastern basin	Total avg.
Soluble phosphorus mg/l	1963-4	0.03	0.01	0.01	0.011
	1967-8	0.04	0.02	0.01	0.018
Organic nitrogen mg/l	1963-4	0.36	0.25	0.24	0.25
	1967-8	0.37	0.32	0.34	0.33
Sediment characteristic					
Total phosphorus mg/g	1963-4	0.76	0.65	0.51	0.62
	1967-8	0.94	0.72	0.93	0.86
Ammonia nitrogen mg/g	1963-4	0.19	0.09	0.07	0.12
	1967-8	0.32	0.25	0.32	0.30

*Lake Erie Environmental Summary 1963-1964, and Lake Erie Surveillance Data Summary 1967-1968.

sewage treatment plants is passed through a series of artificial lakes. These process the effluents so effectively that the final-stage lakes are excellent recreational facilities, providing fishing, swimming, and boating, and the waters released from them are not a burden to the aquatic environment.

If adequate measures were taken to reduce the phosphorus supplies entering Lake Erie, would the lake recover? Unfortunately, this question is largely an academic one today, for there is scarcely any promise that adequate measures will be taken soon. Arthur Godfrey, in a recent radio program said, "The ecologists tell me that Lake Erie is past the point of no return. It is done for. The changes that have occurred there are irreversible." Mr. Godfrey did not identify his ecologists, nor did he ask me about Lake Erie, for I disagree with this view. Lake Erie is a very open system. The western basin is flushed out at a rate of once every two months. The entire lake has a flushing time of about three years. If plant-nutrient contributions were reduced, or if only one nutrient, such as phosphorus, were brought down to a severely limiting level, the stores of phosphorus in the bottom would be transported out in highly significant quantities. I predict

that such measures would show beneficial results within as little as two years, and that most of the phosphorus stored on the bottom would be gone within ten years. I realize that my optimism is not shared by all aquatic scientists. Rainey (1967) presented a mathematical model which tends to support such optimism, but Curl (1967) believes that phosphorus, recycled from the bottom, will plague us for years. But because there is indeed some hope that such methods might provide real solutions to many of Lake Erie's problems, as I sincerely believe, then the voices of Ohio should rise to demand their implementation.

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